

Original Contributions

ENERGY EXPENDITURE, CIGARETTE SMOKING, AND BLOOD PRESSURE LEVEL AS RELATED TO DEATH FROM SPECIFIC DISEASES¹

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In a 22-year followup of 3686 San Francisco longshoremen, the roles of physical activity, cigarette smoking habit, and systolic blood pressure level were evaluated independently in relation to risk of death from a broad range of diseases. Smoking pattern and blood pressure status were established in 1951 and job activity was assessed annually during the followup period. Lower levels of energy expenditure predicted increased risk of fatal heart attack and perhaps of stroke. Heavy cigarette smoking predicted increased risk of death from heart attack, cancer, chronic obstructive respiratory disease, and pneumonia. Higher levels of systolic blood pressure were associated with death from all cardiovascular diseases, diabetes mellitus, and cirrhosis. Tacit to these findings: sedentary living takes its toll largely through heart disease and stroke; the toxicity of cigarette smoking is associated with a broader range of diseases, including heart attack, cancer, and respiratory disease; and higher level of blood pressure related to an even broader range of cardiovascular disease than either of the other characteristics studied.

blood pressure; cancer; cirrhosis; coronary disease; diabetes; physical activity; respiratory disease; smoking

The salutary effect of physical activity on body systems is recognized. Regular vigorous physical exercise promotes physical and mental well being, reduces the frequency and level of characteristics related to heart attack, and leads to cardio-respiratory fitness (1-3). Evidence mounts that

physical exercise reduces the incidence, defers onset, and may diminish the severity of heart attack (4-8). However, there has been insufficient attention to any relation exercise may have to risk of death from other than hypertensive-arteriosclerotic diseases. A study of a population of 3686 San Francisco longshoremen now has assessed independently the roles of vigorous physical exercise, cigarette smoking, and systolic blood pressure level in risk of death from a broad range of fatal diseases. Interest focuses on the role of exercise. Cigarette habit and blood pressure level are examined largely to check consistency of findings from this population with the expected re-

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relationship between these characteristics and the causes of death studied. Estimated relative risks attached to these three predictor characteristics evaluate their influence in particular diseases.

METHODS

From measured oxygen consumption required by job activities of longshoremen (9, 10), the breakpoint between high and low energy expenditure was established arbitrarily at 5.2 kilocalories per minute. On this basis, the average output per 10-hour work-day for low energy workers was rated at 1066 kcal in excess of basal requirements, and for high energy workers at 1976 kcal, subject to variations in rest periods and work style. (Work styles were such that overestimation of high energy kcal levels was more likely than of low energy levels. Therefore, adjustment would tend to narrow the exercise difference and sharpen the implications of energy output vs. heart attack risk, etc.) Adjustment also was made for the frequent slack moments that occurred during heavy work sessions. In this way, low energy workers ranged 4750–8250 kcal/week on the job, while high energy workers were estimated to expend 8500–10,750 kcal/week. Job transfers were checked annually as of the last pay period in June to take account of individual changes in level of energy expenditure, and work activity was compiled as man-years on the job.

In this analysis, each man-year of work was considered as an independent unit observation for purposes of statistical estimation and significance testing. A summary relative risk (11) was used to assess the relationship between cause-specific mortality and each characteristic studied after adjustment for differences in age and the two remaining characteristics. Decedents were classified under the work category recorded at the beginning of each man-year of experience so as to avoid bias from job changes that might have occurred for rea-

sons of ill health shortly before death. In a prior study, the increased risk of fatal heart attack associated with lower level of work-energy output was 70 per cent when job shifts were considered during the 22-year followup period, little different from the 60 per cent when they were not (7). Also, bias due to job shifts in the four years before each man-year of experience has been found to have a negligible effect on the association between energy expenditure and fatal heart attack (12). Consequently, a simpler and substantially less expensive analysis, which does not adjust for bias due to earlier job changes, was used for this report.

Occasionally, job data were missing from the annual record, but restoration was feasible for periods of up to three years without distortion of findings by assuming that men continued working at their last previous known work assignment. These corrections could preserve up to 16 per cent more information than would otherwise have been available. During the followup period there was a general trend of diminishing need for high energy output with modernization of the industry. Therefore, since men without job codes because of absence or illness were categorized by their previous and probably higher energy output level, data restoration generally would dilute rather than reinforce any association between reduced energy expenditure and increased risk of chronic disease. If more than three continuous years of data were missing, subjects were dropped as of the last year recorded. Relative risks were reduced somewhat by inclusion of restored data, but the significance probabilities were strengthened by the larger numbers. Data reported here include the restored information, and probabilities are for two-tailed tests.

All longshoremen aged 35–74 years with known job assignments were enrolled as study subjects at multiphasic screening in 1951, and their man-years of work, by high and low energy classification, were accu-

mulated until death or age 75 or the end of observation (1972). Retirees under age 75 were included as low-energy subjects in this analysis. A supplementary analysis gave similar results whether retirees were included or excluded.

The characteristics of cigarette habit and blood pressure level were recorded at the baseline multiphasic screening but, unlike physical activity, were not reassessed thereafter. Arbitrary breakpoints established for these in analysis were cigarette smoking of one or more packs per day versus less or none, and blood pressure equal to or greater than mean for five-year age group versus lower. Although these personal characteristics might change with age or fashion during the 22-year interval, workers who smoked or had higher blood pressure might be expected to track parallel to their co-workers. Multiphasic screening questions did not distinguish nonsmokers from light smokers, and this coarseness in the smoking classification may have affected adjustments in analysis for other characteristics.

We identified decedents from official records and recoded causes of death using the 7th Revision of the International Classification of Diseases. The following underlying causes of death were treated as potential outcome variables in the present analysis: heart attack (ICD no. 420), stroke (330-332 and 334), hypertension and hypertensive heart disease (440-447), diseases of arteries (450-456), chronic obstructive respiratory disease (501-502 and 526-527), pneumonia (490-493), diabetes mellitus (260), cirrhosis (581 and 462.1), cancer of all sites (140-207), lung cancer (162.1 and 163), accidental death (800-965), and suicide (970-979). All diseases of the circulatory system (400-468) were analyzed only as secondary causes of death and only for men without heart attack as primary cause.

RESULTS

The 22-year followup of the 3686 longshoremen aged 35-74 years generated 55,

635 man-years of observation. Of these man-years, 68.3 per cent comprised low energy job activity (38,014 man-years of observation); 36.0 per cent of the total were contributed by smokers of one pack or more per day (20,011 man-years); and 42.0 per cent by men with systolic blood pressure equal to or greater than mean for age (23,381 man-years). These data express the composite input of all the longshoremen—of all ages, job activities (energy expenditures), smoking persuasions, and blood pressure levels encountered during the study interval. Percentages of man-years per characteristic are not mutually exclusive.

Results (tables 1-3) are expressed as relative risks of death from each specified disease, with and without the adverse side of each characteristic, i.e., low energy expenditure, heavy cigarette smoking, and higher systolic blood pressure. Causes of death are grouped as cardiovascular, respiratory, and metabolic diseases; cancer; and violence. Relative risk for each characteristic is adjusted for differences in age and the other two characteristics. No relationships at significant levels were found for accidental death or suicide.

Energy expenditure

When physical exercise is dichotomized at 5.2 kcal/min (8500 kcal/week), the resulting relative risk of death from all causes is 1.46 (table 1). This signifies a 46 per cent added risk associated with lower levels of energy output, independent of risks added for age, heavy cigarette smoking, or higher systolic blood pressure level. A major risk attached to low energy expenditure is that of heart attack (relative risk 1.97), especially as sudden death (3.32), as has been described before (7). Relative risk of stroke for low energy is 1.62, similar for both thromboembolic and hemorrhagic strokes, but the numbers are not statistically significant.

TABLE 1

Relative risk of death from specific diseases as related to work-energy expenditure among 3686 San Francisco longshoremen in a 22-year followup period, 1951-1972

Underlying cause of death	All longshoremen, total number of deaths (55,635 man- years observation)	Longshoremen with energy expenditure <5.2 kcal/min (38,014 man-years observation)		
		No. of deaths	RR*	p
All causes	1270	1062	1.46	<.001
Heart attack	397	349	1.97	<.001
Sudden	118	107	3.32	<.001
Delayed	113	96	1.63	.066
Unspecified	166	146	1.63	.034
Non-heart attack with mention DCS†	261	230	1.75	.007
Non-heart attack without mention DCS	612	483	1.15	.193
Hypertensive heart disease	48	37	1.05	.903
Stroke	112	98	1.62	.124
Hemorrhagic	60	52	1.73	.200
Thromboembolic	52	46	1.50	.387
Disease of arteries	30	23	0.66	.404
Chronic respiratory disease	25	23	2.01	.292
Pneumonia	29	27	3.86	.087
Diabetes mellitus	14	13	4.46	.203
Cirrhosis	60	49	1.72	.109
All cancers	270	222	1.17	.375
Lung	70	61	1.65	.174
Accidental death	83	57	0.92	.747
Suicide	15	13	2.66	.295
All other causes	187	151	1.27	.262

* Approximate relative risk (odds ratio) adjusted for age, cigarette smoking and systolic blood pressure.

† Underlying cause of death other than heart attack; secondary cause any disease of circulatory system (ICD 400-468).

Where cause of death was not heart attack, low energy output was not a significant risk factor unless disease of the circulatory system was a contributing cause (1.75). However, the listed fatal diseases other than heart attack or stroke represent a wide variety of etiologies, and for some the relative risks accompanying reduced energy output are numerically high though not at statistically significant levels; small sample problems limit detection of any relationship between energy expenditure and these individual diseases. Hypertensive heart disease and diseases of the arteries (generalized arteriosclerosis) seem unrelated to exercise after adjustment was made for differences in age, cigarette habit, and

systolic blood pressure level.

Relative risks of death from chronic obstructive respiratory disease and acute pneumonia are in the range of 2 to 4, and a causal relationship, if any, with low energy expenditure could be reduced pulmonary exchange, but numbers are small and the findings not significant. Of the metabolic diseases, diabetes (4.46) often shares precursive characteristics with heart disease, and cirrhosis (1.72) is often associated with certain aspects of sedentary living; hence, low energy expenditure may be an indirect influence or merely a co-variable. Cancer of all primary sites was unrelated to low energy expenditure, and, of the site-specific cancers studied—lung, pancreas, colorectal,

and prostate—only lung cancer (1.65) shows any suggestion of association. It should be noted that this figure is not significantly different from 1.00 and that it may represent an influence of cigarette smoking data insufficiently controlled in this comparison.

Cigarette smoking

Heavy cigarette smoking (table 2) is related strongly to increased risk of heart attack (2.09), but also to risk of non-heart-attack deaths without mention of circulatory disorder as a secondary cause of death (1.34). Other cardiovascular diseases and metabolic diseases are unrelated to smoking, but chronic obstructive respiratory disease (2.63), pneumonia (2.27), all cancers (1.71), and lung cancer (3.19) are strongly

associated with smoking. These figures are all significant even though nonsmokers and light smokers were not separated in the study, which might have sharpened the observed differences in risk due to use of cigarettes.

Blood pressure

Systolic blood pressure at higher levels (\geq mean for age group) shows its anticipated strong relationship to all the cardiovascular diseases and to death in general (table 3). While higher blood pressure showed no relation to chronic obstructive respiratory disease, the relative risk in pneumonia is 1.86, perhaps an indirect result through degenerative cardiovascular diseases. Both metabolic diseases studied, diabetes mellitus (5.07) and cirrhosis (2.22),

TABLE 2

Relative risk of death from specific diseases as related to cigarette smoking habit among 3686 San Francisco longshoremen in a 22-year followup period, 1951-1972

Underlying cause of death	All longshoremen, total number of deaths (55,635 man-years observation)	Longshoremen smoking 20+ cigarettes/day (20,011 man-years observation)		
		No. of deaths	RR*	p
All causes	1270	537	1.53	<.001
Heart attack	397	198	2.09	<.001
Sudden	118	53	1.63	.008
Delayed	113	57	2.08	<.001
Unspecified	166	88	2.48	<.001
Non-heart attack with mention DCS†	261	94	1.21	.153
Non-heart attack without mention DCS	612	245	1.34	<.001
Hypertensive heart disease	48	14	0.91	.762
Stroke	112	35	1.03	.887
Hemorrhagic	60	17	0.86	.603
Thromboembolic	52	18	1.27	.437
Disease of arteries	30	12	1.51	.267
Chronic respiratory disease	25	14	2.63	.011
Pneumonia	29	15	2.27	.026
Diabetes mellitus	14	2	0.36	.157
Cirrhosis	60	21	1.04	.883
All cancers	270	124	1.71	<.001
Lung	70	43	3.19	<.001
Accidental death	83	35	1.34	.189
Suicide	15	8	2.30	.105
All other causes	187	59	0.92	.592

* Approximate relative risk (odds ratio) adjusted for age, energy expenditure and systolic blood pressure.

† Underlying cause of death other than heart attack; secondary cause any disease of circulatory system (ICD 400-468).

TABLE 3

Relative risk of death from specific diseases as related to systolic blood pressure level among 3686 San Francisco longshoremen in a 22-year followup period, 1951-1972

Underlying cause of death	All longshoremen, total number of deaths (55,635 man-years observation)	Longshoremen with systolic blood pressure \geq mean for age (23,381 man-years observation)		
		No. of deaths	RR*	p
All causes	1270	680	1.70	<.001
Heart attack	397	230	2.06	<.001
Sudden	118	76	2.66	<.001
Delayed	113	56	1.43	.055
Unspecified	166	98	2.20	<.001
Non-heart attack with mention DCS†	261	145	1.81	<.001
Non-heart attack without mention DCS	612	305	1.43	<.001
Hypertensive heart disease	48	40	6.74	<.001
Stroke	112	77	3.16	<.001
Hemorrhagic	60	41	3.03	<.001
Thromboembolic	52	36	3.31	<.001
Disease of arteries	30	18	2.26	.025
Chronic respiratory disease	25	9	0.88	.757
Pneumonia	29	16	1.86	.090
Diabetes mellitus	14	11	5.07	.006
Cirrhosis	60	37	2.22	.002
All cancers	270	115	1.08	.515
Lung	70	26	0.91	.699
Accidental death	83	39	1.22	.366
Suicide	15	8	1.69	.308
All other causes	187	80	1.04	.767

* Approximate relative risk (odds ratio) adjusted for age, energy expenditure and cigarette smoking.

† Underlying cause of death other than heart attack; secondary cause any disease of circulatory system (ICD 400-468).

are correlated significantly with higher levels of blood pressure, but the direction of any causation is obscure. No influence is found on risk of cancer or all other causes.

DISCUSSION

Aside from the limits of small sample problems, and difficulties that arise from interpretation of multiple significance tests, the described multivariate analysis of the longshoremen's experience shows that all three high-risk characteristics—cigarette smoking, low energy output, and higher systolic blood pressure—are independently influential in specific diseases, uncertain as to role in others, and apparently not implicated in some. This differentiation may warrant further assessment of physical ac-

tivity as an intervention measure, since both smoking and blood pressure already have been extensively studied in relation to many diseases.

The summary relative risk and associated statistical significance tests indicate an independent relationship of each of the three characteristics to death from a variety of specific causes. All three adverse characteristics show similar strength in relation to total death and to death from heart attack, but differences appear with relation to other diseases. In this population of longshoremen, low energy expenditure is associated with non-heart-attack deaths only where disease of the circulatory system is mentioned as a contributing cause, implying that sedentary living exacts its toll

chiefly through heart disease and perhaps stroke. Cigarette smoking, through its various toxic processes, is associated with death from a broad range of diseases—heart attack, cancer, and respiratory disease. High systolic blood pressure is related to an even broader range of cardiovascular disease than either of the other characteristics studied.

REFERENCES

1. Mann GV, Garrett L, Long A: The amount of exercise necessary to achieve and maintain fitness in adult persons. *South Med J* 64:549-553, 1971
2. Cooper KH: *The New Aerobics*. New York, Bantam Books, 1970
3. Froelicher VF: The effects of chronic exercise on the heart and on coronary atherosclerotic heart disease: A literature survey. *In Cardiovascular Clinic*. Edited by A Brest. Philadelphia, PA, FA Davis Co., 1976, pp 3-37
4. Morris JN, Heady JA, Raffle PAB, et al: Coronary heart disease and physical activity of work. *Lancet* 2:1053-1057, 1111-1120, 1953
5. Morris JN, Chave SPW, Adam C, et al: Vigorous exercise in leisure-time and the incidence of coronary heart-disease. *Lancet* 1:333-339, 1973
6. Shapiro S, Weinblatt E, Frank CW, et al: Incidence of coronary heart disease in a population insured for medical care (HIP): Myocardial infarction, angina pectoris, and possible myocardial infarction. *Am J Public Health* 59:1-101, 1969
7. Paffenbarger RS, Jr, Hale WE: Work activity and coronary heart mortality. *N Engl J Med* 292:545-550, 1975
8. Paffenbarger RS, Jr, Wing AL, Hyde RT: Physical activity as an index of heart attack risk in college alumni. Unpublished manuscript
9. Passmore R, Durnin JVGA: Human energy expenditure. *Physiol Rev* 35:801-840, 1955
10. Hale FC, O'Hara JJ: *An Engineering Analysis of Cargo Handling. X. Energy Expenditure of Longshoremen (Report 59-20)*. Los Angeles, CA, Department of Engineering, University of California, June, 1959
11. Mantel N, Haenszel W: Statistical aspects of the analysis of data from retrospective studies of disease. *J Natl Cancer Inst* 22:719-748, 1959
12. Brand RJ, Paffenbarger RS, Sholtz RI, et al: Work activity and fatal heart attacks studied by multiple logistic risk analysis. Unpublished manuscript